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Detailed Explanation of the Invention

1. Name of the Invention

Beam Focusing (Converging) Lens

2. Scope of the Claims

Beam focusing lens characterized by the fact that the first and the second positive meniscus lenses made from zinc selenide are installed so that their convex surfaces face the direction of the incident light beam and when the total system focal distance is denoted as F, the curvature radius that forms the above described second positive meniscus lens on one side is within the range of 1.5 F to 0.5 F, and the other side it is within the range of 2.0 F ~ 0.5 F.

3. Detailed Explanation of the Invention

Technical Field of the Invention

The present invention is an invention about a beam converging lens that is used for beam focusing in order to focus laser beams, etc. on a microscopic spot.

Structure of Previous Technology Examples and Their Problem Points

Laser beam generated from laser generating oscillating device is focused on a microscopic spot by using a light focusing lens and the high speed, precision cutting of metals or ceramic, etc., non-metal materials, can be performed.

In this case a high power laser beam is focused by an external optical system that is installed outside of the laser generating oscillating device and by that the power density becomes unusually high at $10^6 \sim 10^7$ W/cm2 and a carbon oxide gas laser oscillating at a wavelength of approximately 10.6 μm is used appropriately.

In Figure 1 a three-dimensional diagram of the curvature type laser processing device according to the previous technology, which utilizes an external part optical system, is shown.

In the Figure, 1 represents the carbon oxide gas laser oscillation device, 2 represents the leaser beam that is propagated from the laser oscillating device, and in order to fix the reflecting position, the reflective mirror 3, used in order to guide the straightened laser beam to the cutting process position, is fixed securely inside the holder 4. The reflected laser beam is focused on the processing position 7 on the surface of the material subject to the processing through a normal light focusing lens 5 and the precision cutting is performed. Regarding the material of the light focusing lens 5, it is possible to use Ge, GaAs, CdTe, ZnSe, etc., materials which do not absorb the 10.6 μm oscillation wavelength light of the carbon oxide gas laser, however, usually, there are many cases where ZnSe is used because of the fact that it has strong behavior relative to the usual thermal expansion impact, has low laser bean absorption ratio and has good visibility properties relative to visible light. However, the ZnSe is an expensive material and because of that in the past light focusing lenses have been used that have been formed from single individual lenses.

Regarding Figure 2, by a single lens manufactured from ZnSe, which is representative of the lenses used according to the previous technology, in the case of Figure 2 (a), by using the easy to manufacture plano-convex lens 15, where the lens focal distance is made to be f mm, and relative to 10.6 μm wavelength, it has a refraction ratio of 2.40 and because of that the lens surface curvatures are correspondingly $\gamma 151 =\sim 1.4$ f mm, $\gamma 152 = \infty$. In the case of this plano-convex lens 15, the side on the other side of the curved surface is a flat surface and because of that the manufacturing is easy, and because of that the maintenance methods are easy, however the aberration is large. In the case of the single lens 25 in Figure 2 (b), it has the focusing meniscus shape that has small abberation and because of that if the focal point distance of the lens is denoted as f1 mm, the surface curvature ratio of the lens is made to be $\gamma 251 =\sim 0.9$ f mm, $\gamma 252 = 2.4$ f mm, and because of that it is a lens that as a single lens has small abberation. However, even in the case of the single lens 25 shown according to Figure 2 (b), the focusing spot cannot be made to be sufficiently small. For example, in the case when a laser beam with Gaussian distribution of the radius 16 ϕ, is focused by using an f=1.5" meniscus single lens, the side direction spherical surface abberation remains approximately Δy=50 μm.

Goal of the Present Invention

The present invention is an invention that has as a goal to solve the above described drawback points and because of that it has as a goal to conceive a lens where the abberation is small, and where the power at the time of the processing is increased and the processing precision is improved.

Structure of the Present Invention

The present invention is in invention where in order to achieve the above described goal the following is suggested: a beam focusing lens characterized by the fact that the first and the second positive meniscus lenses made from zinc selenide are installed so that their convex surfaces face the direction of the incident light beam and when the total system focal distance is denoted as F, the curvature radius that forms the above described second positive meniscus lens on one side is within the range of 1.5 F to 0.5 F, and the other side it is within the range of 2.0 F ~ 0.5 F.

Explanation of a Practical Implementation Example

In Figure 3 the beam focusing lens, which is the first practical embodiment example of the present invention, and its light path diagram, are presented.

In the case of this practical implementation example it has a structure that is formed by combining the shown as 31 and 32 two positive meniscus lenses. As the material for these positive meniscus lenses 31 and 32, ZnSe is used. This is based on the fact that the spectral transmissivity is within a wide range of 0.48 μ ~ 18 μ, because of the provided anti-reflective layer, and it shows an approximately 90% or higher flat trend, and because of that at the time of normal light, the lens insertion, adjustment and measurement are easy, the break threshold value is high , the thermal resistance properties are good, and especially, the refractive ratio at 2.4028 (λ=10.6μ) is high, and it is quite effective as a light focusing lens material used for the focusing of carbon oxide laser beam.

Regarding the first positive meniscus lens 31, it has a structure where, the curvature radii are R1 and R2 and the lens thickness is d1, and for the second positive meniscus lens 32, the curvature radii are R3, R4, and the lens thickness is d3, and the space between the two lenses is only the gap of the distance d2.

Then, at the time when the lens design is performed, the following become necessary conditions: the F number is increased, the diffraction abberation is reduced, and a balance with the light beam following aberration amount is preserved, and not only that but also, the number of the structural components is made to be small and a microscopic spot is produced. Then, it is necessary that, first, the spherical surface aberration, the side aberration for the laser beam generated diffusion angle, the diffraction aberration relative to the F number, the focal point depth on that, the working distance, etc., are taken into consideration and the spot diameter is determined. Regarding the lens structure, a lens is produced where in correspondence to a refractive index of n=2.4028, a tertiary aberration coefficient is obtained, and the distance between the minimum structure component number two lenses is made to be small and the corresponding aberration distribution amount is equalized, and not only that but also, the produced lens system becomes a system that does not contain a concave lens. Especially, regarding the first lens 31, as the convex meniscus, a convex surface is made that is facing the incident beam side, and in the second lens 32, relative to the former converging light beam, centripetally, an aplanatic surface is placed, and the projected light beam is focused on approximately the

spherical center of the projection surface. At this time, the curvature radius R3 of the second meniscus lens 32 needs to be within the range of 1.5F to 0.5 F. Here F is the total system focal point distance. Namely, at the time when the curvature radius R3 exceeds the upper limit of 1.5 F, the spherical surface aberration curvature line collapses to the negative side, and on the contrary, the sine condition curvature line moves to the positive direction, and the generated diffusion angle aberration becomes asymmetrical, and the frame flare is increased and the spot diameter becomes unclear. Also, at the time when it becomes lower than the lower limit of 0.5 F, both curve lines together are collapsed to the negative side, and the same way, the spot diameter is increased and because of that it is desired that the R3 is set within the above described range.

Regarding the other second meniscus lens 32 curvature radius R4, it is necessary to be selected within the range of 2.0 F to 0.5 F. Namely, at the time when the curvature radius R4 exceeds this upper limit value of 2.0 F, the spherical surface aberration curve line collapses to the negative side and on the contrary, the sine condition curve line moves to the positive side, and also, at the time when it is below the lower limit of 0.5 F, both curve lines together are collapsed to the negative side. In either case, the generated diffusion angle aberration amount becomes asymmetrical, and the flare amount is increased and the spot condition becomes unclear, and consequently, it becomes a condition where a high precision laser beam spot is not obtained.

After that, as detailed example, for the beam focusing lens with the details below, the tertiary aberration coefficient was obtained and it was according to the shown in the table below.

The total system focal point distance F=1.0
The curvature radii of the first positive meniscus lens 31

	R1 = 1.55524
	R2 = 3.33672
Lens thickness	d1 = 0.11131
Refractive index at λ = 10.6 μ	
	n1 = 2.4028
Distance between the lenses	d2 = 0.002336
Refractive index in air	n2 = 1.00

The curvature radii of the second positive meniscus lens 32

	R3 = 0.68984
	R4 = 0.83942
Lens thickness	d3 = 0.11131
Refractive index at λ = 10.6 μ	
	N3 = 2.4028

Table: Tertiary aberration coefficient

	Spherical surface abberation coefficient	Frame abberation coefficient	Anastigmatic aberration coefficient	Image surface curve coefficient	Correction curve aberration coefficient	Baseball coefficient
	Av	Bv	Γv	□v	Ov	Pv
1	0.06459	0.10045	0.15622	0.53161	0.82679	0.37638
2	0.01408	-0.06987	0.34679	0.17182	-0.85277	-0.17496
3	-0.05576	-0.066970	-0.08713	0.75917	0.94903	0.84631
4	0.00026	0.01327	-0.00005	-0.01905	-0.97094	-0.69550
5	0.02317	-0.02585	1.09233	1.44356	-0.04789	0.35123

Regarding this practical implementation example, the spherical surface aberration curve (SA) and the sine condition curve (SC) practically measured values are shown in Figure 4 (a) and the lateral aberration curve practically measured values for the generated diffusion angle 4 are shown in Figure 4 (b).

As it is understood from the figures, the spherical surface aberration, the sine condition both show low values, and also, the lateral aberration curve shows good symmetrical properties.

Also, in the case when the beam light focusing lens according to this present practical implementation example is used appropriately for laser processing, if the Gaussian distribution possessing laser beam is focused in the vicinity of the focal point distance, the composite spot becomes a fine spot with a diameter of approximately 90 μm ϕ, and compared to the case when the shown according to Figure 2 (b), meniscus single lens according to the previous technology, has been used, the power density becomes $130^2/90^2 = \sim 2.1$ times, and the cutting processing, the perforating processing precision becomes approximately 2.1 times better.

Results from the Present Invention

According to the above described, in the case of the present invention, it is invention whereby a beam focusing lens, characterized by the fact that the first and the second positive meniscus lenses made from zinc selenide are installed so that their convex surfaces face the direction of the incident light beam and when the total system focal distance is denoted as F, the curvature radius that forms the above described second positive meniscus lens on one side is within the range of 1.5 F to 0.5 F, and the other side it is within the range of 2.0 F ~ 0.5 F, has been suggested. And by that it is possible to obtain low aberration and a microscopic spot, and it is possible to design the increase of

the power density at the time of the laser processing and an improvement of the processing precision.

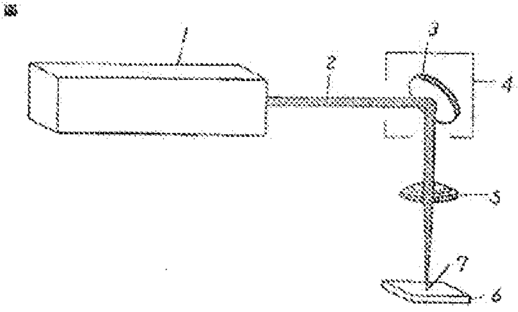
4. Brief Explanation of the Figures

Figure 1 represents a schematic diagram of the typical laser processing equipment according to the previous technology. Figure 2 (a), (b), represent schematic diagrams of the beam light focusing lens according to the previous technology. Figure 3 is a diagram showing the beam light focusing lens according to the present practical implementation example and its light path diagram, Figure 4 is a diagram showing the aberration curvature line of the present practical implementation example, (a) represents the spherical surface aberration curvature line and (b) represents the lateral aberration curvature line.

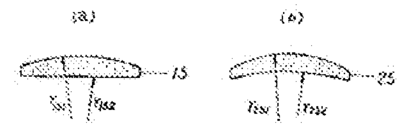
31...first positive meniscus lens,
32.......................second positive meniscus lens.

Patent Assignee: Matsushita Electric Industries Co. Ltd.

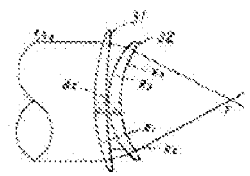
第 1 図



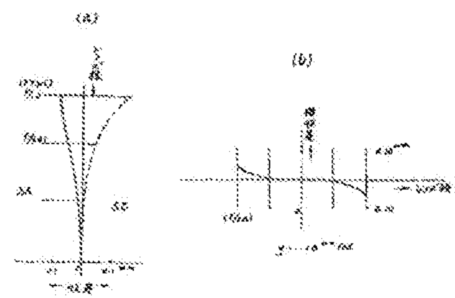
第 2 図



第 3 図



第 4 図



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発明の名称　ビーム集光用レンズ

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明　　細　　書

1、発明の名称

ビーム集光用レンズ

2、特許請求の範囲

セレン化亜鉛よりなる第1及び第2のメニスカスレンズを、ビーム入射光向に対してそれぞれ凸面を向けるように配置し、全系の焦点距離をFとしたとき、前記第2のメニスカスレンズを形成する曲率半径の一方を1.0Fと0.6Fの間に、他方を2.0Fと0.8Fの間に設定したことを特徴とするビーム集光用レンズ。

3、発明の詳細な説明

産業上の利用分野

本発明は、レーザビーム等を微細スポットに集光させるためのビーム集光用レンズに関するものである。

従来例の構成とその問題点

レーザ発振器からのレーザビームを集光用レンズで微細スポットに集束させ、金属やセラミック等の難加工材料の穴あけ、精密切断が行われている。この場合、パワーが高く、レーザビームをレーザ発振器外に設置した外部光学系で集光することによりパワー密度が$10^6 \sim 10^8$ W/cm^{2}と非常に高くなり、波長が約10.6μmで発振する炭酸ガスレーザがよく使用されている。

第1図に外部集光学系を使用した、従来の典型的なレーザ加工装置の概観図を示す。

図において、1は炭酸ガスレーザ発振器、2はレーザ発振器から発振したレーザビーム、3は発振して来たレーザビームを加工位置まで導くための反射鏡で、反射方向を調整するために、この反射鏡3はホルダー4内に調整可能に固定されている。反射されたレーザビームを集光レンズ5で被加工物6上の加工位置で微細スポットに集束させ、精密加工を行う。集光レンズ5の材料は炭酸ガスレーザの発振波長である10.6μmの光を吸収しないようなGe, GaAs, CdTe, ZnSe等が用いられるが、熱的熱衝撃による損傷が少なく、レーザビームの吸収率が低く、可視光に対する透過性が良いZnSeが用いられることが多い。しかし

ながらZnSeは高価な材料であるので従来は1枚の単レンズから成る集光レンズを用いていた。

第2図は従来用いられている代表的なZnSe製の単レンズで、第2図(a)は製作が容易なプラノ・コンベックスレンズ1aで、レンズの焦点距離をfmmとし、10.6μmの波長に対して屈折率2.4であるからレンズ表面の曲率半径はr_1=1.4fmm、r_2=∞で与えられる。このプラノ・コンベックスレンズ1aは片側の曲面が平面であるので製作が容易で、保持の仕方が容易であるが、収差は多い。第2図(b)の単レンズ2bは収差を少くした非球面メニスカス形状で、レンズの焦点距離をfmmとすると、レンズ曲面曲率をr_1=0.8fmm、r_2=2.4fmmにすることにより単レンズとしては収差が少いものである。しかしながら第2図(b)の単レンズ2bでも集束スポットを十分小さく出来ない。たとえば直径10mmのガウス分布のレーザビームをf=63.5mmのメニスカス形単レンズで集束した場合には焦点の集束径は約80μm程度である。

発明の目的

本発明は上記の点を解消するもので、収差が少なく、レーザ加工機のパワーの増大、加工精度の向上をはかることを目的とするものである。

発明の構成

本発明は上記目的を達成するもので、セレン化亜鉛よりなる第1及び第2の正メニスカスレンズを、ビーム入射光方向に対してそれぞれ凸面を向けるように配置し、全系の焦点距離をFとしたとき、前記第2の正メニスカスレンズを構成する曲率半径の一方を1.5Fと0.5Fの間に、他方を2.0Fと0.5Fの間に設定したことを特徴とするビーム集光用レンズを提供するものである。

実施例の説明

第3図に本発明の一実施例であるビーム集光用レンズとその光路図を示す。

本実施例は3_1、3_2で示す2枚の正メニスカスレンズの組み合わせより構成されている。これら正メニスカスレンズ3_1及び3_2の材料としては、ZnSeを使用した。これは分光透過率が、反射防止膜を施すことにより、0.4μm～20μmの広範囲に亘り、およそ90%以上のフラットな特性を示すため、可視光でのレンズ組込、調整、検査が容易であること、機械的強度が高く、耐熱性が良いこと、更に屈折率が2.4026(λ=10.6μ)と高く、炭酸ガスレーザービーム集光用レンズ素材としては、かなり有用であることに基づいている。

第1の正メニスカスレンズ3_1は曲率半径R_1、R_2、レンズ厚はd_1、第2の正メニスカスレンズ3_2は曲率半径R_3、R_4、レンズ厚d_3であり、二つのレンズ間は距離d_2だけ離して構成されている。

そこでレンズ設計を行うに当っては、パワーを上げ、球面収差を減らし、光線追跡収差特性とのバランスを保ち、しかも構成枚数を少くし、最小スポットを作ることが必要条件となる。そこで先ず球面収差、レーザービーム発散角における収差、チャンバーに封止した球面収差、それに焦点深度、ワーキングディスタンス等を考慮してスポット径を決めなければならない。レンズ構成については、屈折率n=2.4026に対応し、全系収差係数を求め、最少構成枚数二枚レンズの収差を小さくし、夫々の収差分担量を均等化し、しかも凹レンズを含まないレンズ系を得ることになる。更に第一レンズ3_1は、凸メニスカスとして、入射ビーム側に凸面を向け、第二レンズ3_2には、前者の収差光束に対して、ほぼアプラナティック条件を満足し、出射光束が、出射側の点の附近に集光する様にする。この為第2のメニスカスレンズ3_2の曲率半径R_3は1.5Fと0.5Fの間に選ばねばならない。ここでFは全系の焦点距離である。すなわち曲率半径R_3が上限1.5Fを越える時は、球面収差曲線が負側に倒れ、更に正弦条件曲線が近軸方向へ移動し、残存収差が非対称となり、コマフレアーが増大し、スポット像が非対称になる。又下限値0.5F以下になる時には、両曲線共に負側に倒れ、同様にスポット径が増大するので、R_3はこの範囲内にあるのが望ましい。

一方第2のメニスカスレンズ3_2の曲率半径R_4は2.0Fと0.5Fとの間に選ばねばならない。すなわち曲率半径R_4がその上限値2.0Fを越える時

次は、従前の如く曲線が負側に倒れ、逆に正弦条件曲線が＋方向へ移動し、又、下部のＳＦにて更にある場合は、両曲線共に負側へ倒れる。何れの場合においても、収差曲線が大幅な傾きとなり、フレアー成分が増大し、スポット形状がタテブー状となり、従ってレーザービームの良好なスポットが得られないことになる。

次に具体例として、

全系の焦点距離 f＝1.0

第1の正メニスカスレンズ31の曲率半径

R_1 ＝1.66624

R_2 ＝3.93072

レンズ厚 d_1 ＝0.11131

λ＝1000nmにおける屈折率

n_1 ＝2.4028

レンズ間隔 d_2 ＝0.003356

空気の屈折率 n_2 ＝1.00

第2の正メニスカスレンズ32の曲率半径

R_3 ＝0.68384

R_4 ＝0.93342

レンズ厚 d_3 ＝0.11131

λ＝1000nmにおける屈折率

n_3 ＝2.4028

のビーム集光用レンズについて、三次収差係数を求めると下表のようになる。

以 下 余 白

表　三次収差係数

	球面収差係数	コマ収差係数	非点収差係数	像面湾曲係数	歪曲収差係数	ペッツバール和
	A_ν	B_ν	Γ_ν	C_ν	Φ_ν	P_ν
1	0.05465	0.10046	0.14672	0.62161	0.02614	0.37898
2	0.01408	−0.06697	0.34679	0.17182	−0.95277	−0.17496
3	−0.05676	−0.16970	−0.00719	0.72917	0.94203	0.84021
4	0.00026	0.01327	−0.00005	−0.01906	−0.07094	−0.59850
Σ	0.02317	−0.02586	1.08322	1.44256	−0.04789	0.25123

本実施例について、球面収差曲線（SA）及び正弦条件曲線（SC）の実測値を第4図(a)に、非点収差における像面湾曲の実測値を第4図(b)に示す。

図からもわかるように、球面収差、正弦条件ともに小さな値を示し、すぐれた収差補正が良好に性能を示した。

また本実施例のビーム集光用レンズをレーザ加工に応用した場合、ガウス分布のレーザビームを焦点距離f＝で集束させると、焦点スポットは径にて約50μmの良好なスポットとなり、第3図に示した従来のメニスカスレンズを使用した場合に比べてパワー密度で130°/50°に向上することとなり、切断加工、溶接加工の精度が著しく良くなった。

発明の効果

以上のように本発明は、ルンゲ条件部よりなる第1及び第2の正メニスカスレンズを、ビーム入射方向に対してそれぞれ凸面を向けるように配置し、全系の焦点距離をfとしたとき、各部材の

正メニスカスレンズを形成する曲率半径の一方を1.5Fと0.8Fの間に、他方を2.0Fと0.6Fの間に設定したことを特徴とするビーム集光用レンズを提供するもので、収差が小さく微細スポットを得ることができ、レーザ加工時のパワー密度の増大・加工精度の向上を図ることができる。

4、図面の簡単な説明

第1図は従来の典型的なレーザ加工装置の構成図、第2図(a)、(b)は従来のビーム集光用レンズの断面図、第3図は本発明の一実施例であるビーム集光用レンズとその光路図、第4図は本実施例の収差曲線を示す図で、(a)は球面収差曲線と正弦条件曲線、(b)は非点収差曲線である。

31……第1の正メニスカスレンズ、32……第2の正メニスカスレンズ。

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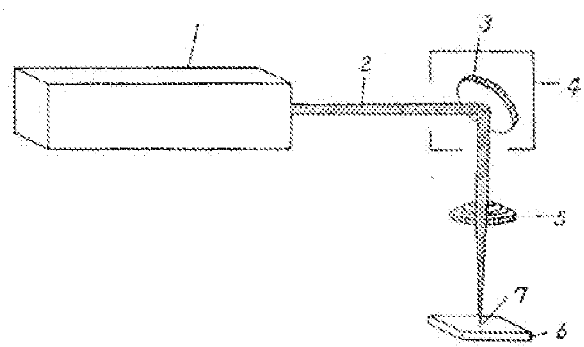
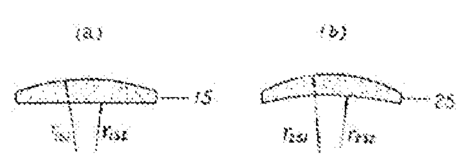
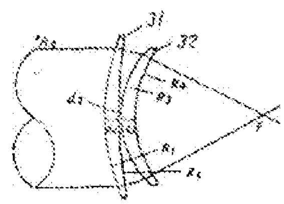
第1図



第2図



第 3 図



第 4 図

(a)